Industrial Energy Efficiency:

Using Data Analytics
to
Monitor Excess Pump Use

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Declaration of authorship

I declare that this dissertation is my own work and that it contains no material written or published by any other person expect where referenced and acknowledged.

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ABSTRACT

Pumping is a common function in almost all industrial processes and it is often a significant contributor to energy consumption and maintenance costs. In large continuous processes there can be many hundreds of pumps installed, which must be monitored and controlled by control room operators along with potentially thousands of other process variables. In a complex operating environment the status of relatively simple devices, such as pumps, can easily be overlooked. This can result in more pumps being run than is required, which in turn results in results in higher energy cost and increased maintenance requirements. This dissertation details the process, methods and results obtained from a project that used industrial process control information technology to monitor the number of running pumps, produce notifications, and energy calculations when excessive drive use was detected.

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ABBREVIATIONS

DCS	Distributed Control System
DVM	Daily Visual Management
g	grams
g/l	grams per litre
GJ	Giga Joule
GW	Giga Watt
ISC	Inter-Stage-Cooler
KPI	Key Performance Indicator
LTD	Liquor to Digestion
kW	kilo Watt
MES	Manufacturing Execution System
ml	millilitre
MM	Mining and Milling
MT	Mega Tonne
MW	Mega Watt
MWh	Mega Watt Hour
STEM	Short Term Electricity Market
VSD	Variable Speed Drive
WA	Western Australia

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Thanks is owed to the many people at Alcoa who freely gave their time and allowed me access to their production management systems. While working at Alcoa I found close knit teams and many individuals with an enthusiasm for new ideas and improvements – it is privilege to have worked with them.

To Fitri, my ever patient wife for her support and love through this long process.

Lastly, but never least, special thanks to young Oliver who has often pulled me from my desk to remind me of lives true priorities.

1 INTRODUCTION

The use of pumps to transport liquids and slurries is common in metallurgic processes such as alumina refining, iron ore mining, precious metals, nickel and many others. Transportation of large volumes of high density slurries requires significant amounts of electrical energy, with pumps often running into the hundreds and even thousands of kW. In addition to high energy consumption slurries are erosive which results in rapid mechanical and structural wear requiring frequent outages for maintenance and part replacement.

In order to maintain high flow rates, which is often a key performance metric, pumps are designed in parallel sets to provide redundancy and flexibility to processes that often run continuously. Within a pump set it is rarely, if ever, required that every pump should run simultaneously, the sets are designed so that pumps can be offline for maintenance or available at short notice in the event of the failure of an operating pump. At times this operational flexibility can result in more pumps being run than is necessary to achieve the required process flow, which leads to excess energy use, increased maintenance requirements and cost. Detecting excess pump use is not necessarily easy as operations personnel are required to monitor large numbers of complex process variables and respond to frequent process disturbances. Pump status can easily be over-looked in a complex process environment.

1.1 THE SOLUTION

Increasing awareness of excess pump use and the associated additional energy cost would provide a measurable incentive to reduce pump use, improve process energy efficiency and ultimately reduce operating costs. Many modern industrial processes utilise advanced software and computing technology to control and monitor process performance. A common component in these process control systems is a data historian that stores process data at regular time intervals. This historical data can be made available for near-term process performance monitoring or can act as a rich repository for complex analysis of process performance over many months or years.

This project involved development of a server based application to utilise the historical process data at an Alumina Refinery to monitor pump status and detect excess use within pump sets and calculate the energy and dollar cost over a production day. A custom software application was developed that takes a snapshot of the drive statutes at 6:00 am each day, calculates the number of excess drives running, calculates an estimate of the additional electricity consumed and an additional cost[1] estimate based on the 1 day average of the Short Term Electricity Market (STEM) price. The results are made available in a graphical web based format that is accessible by refinery operations, engineering and management.

[1] The dollar cost values have not been included in this dissertation for commercial reasons.

2 LITERATURE REVIEW

The literature review for this project was limited as no articles or reports were found that related directly to using Manufacturing Execution Systems (MES) technology to monitor excess pump use. The project was essentially an engineering effort and it is possible that similar applications have been developed at other sites, but these efforts appear not to be widely reported. Two literature sources were found to be of relevance to the project: The Energy Efficiency Assessment Handbook and a paper published by Katharina Bunse et al. in the Journal of Cleaner Production. The handbook proved to be of practical assistance and the journal article serves to highlight the untapped potential for MES to improve energy performance in industrial processes.

The primary literature source referenced in this project is the Energy Efficiency Opportunities Assessment Handbook. The handbook was published by the Australian Government Department of Resources, Energy and Tourism to assist companies undertaking energy assessments under the now revoked Energy Efficiency Opportunities Regulations 2006. The content of the handbook is based on experiences of organisations that have successfully completed energy efficiency assessments. A recommended process for conducting an energy assessment is detailed along with case studies of successful energy assessment projects. The handbook is primarily aimed at organisations undertaking broad-based investigations to identify and evaluate any number of potential projects. This project had a single specific aim – identify excess pump use and quantify the cost – nevertheless the handbook was still relevant and useful for the project. In the handbook communication and management sponsorship were described as “an essential part of an assessment” (Assessment Handbook 2011, viii); and understanding energy use as “a critical stage in the assessment process” (Assessment Handbook 2011, viii). These points were of crucial value to the project and were incorporated into the process used to define, engineer and deploy a working excess drive assessment application to the client.

A paper by K. Bunse et al., Integrating energy efficiency performance in production management – gap analysis between industrial needs and scientific literature; investigates the use of Manufacturing Execution Systems in industrial energy performance. Bunse found that there is a gap between industrial technology capability and actual implementation in relation to energy efficiency (Bunse et al. 2011, 667). Bunse makes key points on criteria that MES applications should address in order to improve energy efficiency, some of these points related directly to this project:

- Present energy efficiency in dollar value.
- Use KPIs to track improvements.
- Equipment should communicate energy use data.
- Use industrial information technology (MES) to provide business leaders with information on energy performance.

  (Bunse et al. 2011, 674)

3 ALUMINA INDUSTRY IN WA

Alumina refining is a large and well established industry in Western Australia (WA) with three refineries operated by Alcoa of Australia at Kwinana, Pinjarra and Wagerup and one operated by South 32 at Worsley. The Bayer process is the main industrial method for the processing of bauxite into alumina and it is used at all four Western Australian alumina refineries. The refineries have a combined annual production capacity of 13.4 million tonnes (AAC 2010b, f) and produced approximately $5 billion dollars in revenue in 2014-15 (DMP 2014-15). The Alumina refining process is highly energy intensive with Pinjarra requiring approximately 11.9 GJ (Institute 2015) to produce 1 tonne of alumina worldwide. When the high energy consumption is combined with high labour and regulatory costs it makes it difficult for Western Australian alumina producers to compete with lower cost competitors in other global regions. Reducing costs through improved energy efficiency is an important and continuous area of focus for WA alumina refiners.

The Alumina refineries are supplied with bauxite from nearby mining operations at Boddington, Huntly and Willowdale producing 45 MT of bauxite per annum (AAC 2010a, e) with a purity of approximately 30% (AAC 2010c). The bauxite is constituted into a slurry at the milling stage of the process, at this point of the Bayer process the slurry is at its greatest density and therefore requires significant energy to transport and due to the highly erosive nature of the slurry there is a high maintenance cost to replace worn pump parts. The slurry mass can be estimated considering that in a typical operation there is approximately 1000 g of bauxite in every litre of slurry leaving the mills, bauxite has a specific gravity of 2.4 and the liquor used to constitute the slurry has a specific gravity of 1.25.

The volume of bauxite in 1 L of slurry $= \frac{1000}{2.4} = 400\ ml$

Therefore there is 600 ml of liquor in 1 L of slurry and the mass of the liquor $= 600 \times 1.25 = 750\ g/L$

The total mass of 1 L of slurry is therefore 1000 g of bauxite plus 750 g of liquor giving a total mass of 1750 g per litre.

The 45 MT of mined bauxite is converted to a high density slurry at a ratio of 1.75 tonnes of slurry to each tonne of bauxite, giving an estimated 79 MT of slurry to be pumped every year through Western Australian alumina refineries. This is a considerable mass to be transported by pumping that requires significant energy.

3.1 PINJARRA

The Pinjarra alumina refinery has been in operation since 1972 and has an annual production capacity of 4.2 MT. Since starting operation Pinjarra has undergone a number of expansion and efficiency upgrades to make it one of the largest and most efficient refineries in the world (AAC 2010d). Alcoa recently received environmental approval to expand production at Pinjarra to 5 MT per annum, which will be achieved through a variety of expansion and efficiency improvement projects (Evans 2015).

Pinjarra uses the Bayer Process to refine the locally mined bauxite to alumina. There are 9 major operating centres at Pinjarra covering the Bayer and ancillary processes such as residue and power house. These processes are briefly described below:

- MM Mining and Milling mines the bauxite from nearby mines, transports the bauxite to the refinery by overland conveyors and then stockpiles and mills the bauxite for supply to the Bayer process.
- Digestion constitutes the bauxite into a slurry using caustic soda. The slurry is then feed through a series of digesters to dissolve the alumina.
- Clarification separates the mud from the Alumina rich liquor. The mud is then sent to the residue area for long term storage and the liquor is sent to the oxalate.

- Oxalate removes organic impurities from the liquor.
- Precipitation crystallises the alumina to extract it from the liquor stream.
- Filtration separates the alumina crystals from the spent liquor.
- Calcination heats the alumina crystals to remove water that is chemically joined with the alumina crystals.
- Power House provides steam and electricity to the process plants.
- Residue treats and stores the residue mud from the process.

3.2 SIZE OF THE PROBLEM AT PINJARRA

Alcoa have an accurate understanding of overall consumption of electricity and gas but often lack detailed information on energy consumption at a process unit level. The plant was designed and constructed in the 1960s and 70s when electronic instrumentation and microprocessor based control systems were used sparingly. Over time the process monitoring and control systems have been improved and substantially expanded. However the expansion of the instrumentation and control systems have focused on process improvements with energy monitoring not being of primary concern. The lack of energy instrumentation makes accurate monitoring of energy consumption at a process element level impossible, but considering that the process is continuous and relatively stable reasonable estimates can be made. The Pinjarra Alumina Refinery has approximately 900 electric drives spread across its main operating centres with the total installed capacity of the drives estimated at 122 MW with an average drive capacity of approximately 136 kW. The largest drive is 4200 kW and the smallest is less than 1 kW.

Average electricity consumption on site is approximately 90 MW per hour or 2.16 GW hours per day, with the majority of power consumption attributed to electric drives. Providing refinery management with the means to easily identify excess pump use should result in reduced electricity consumption.

Considering that several pumps exceed 100 kW in capacity, even a small reduction in excess pump use could result in significant annual energy and cost savings.

Reducing energy cost through greater efficiency is a part of Alcoa's business improvement plan and is a continuous effort. Reducing excess drive use is an operational culture change best achieved by increasing awareness of excess use and its cost at an operational level. Increased awareness achieved through presenting excess use numbers and cost in a clear and easily accessible format.

4 DRIVE MONITORING PROJECT PHASES

The energy efficiency assessments undertaken in this project were based on the guidelines detailed in the Energy Efficiency Opportunities Handbook. The handbook was published by the Australian Government to support companies undertaking energy efficiency assessments under the requirements of the now repealed Energy Efficiency Opportunities Regulations 2006. The handbook details a seven-stage assessment process which is detailed below in Figure 1 – Assessment Process Overview (Assessment Handbook 2011, 2).

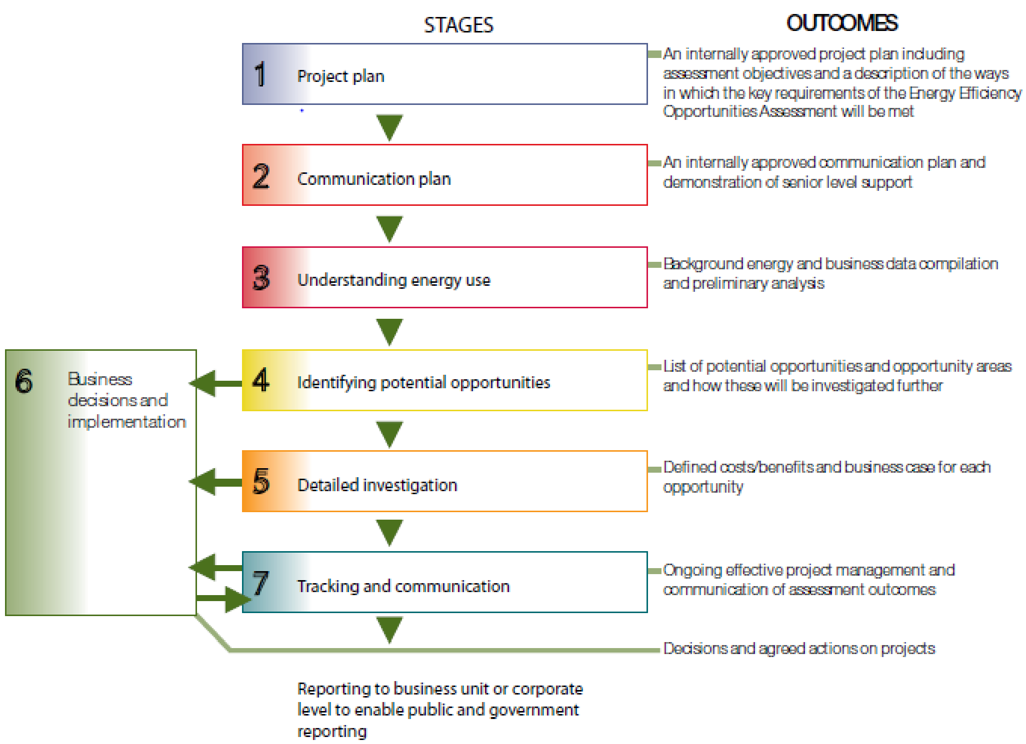


Figure 1: Assessment Process Overview

The assessment process detailed in the handbook is intended as a best practice guide that should be modified to suit the specific needs of any individual project. For this project the process was modified to cover 6 main phases from planning to deployment of the application into Alcoa's daily operations – these are shown below in Figure 2 – Project Phases.

Figure 2: Project Phases

Each phase of the project is briefly described below:

- Phase 1 covered introductory meetings with Alcoa and identifying the subject for the dissertation.
- Phase 2 involved obtaining drive information from Pinjarra and identifying the drives to be included in the project.

- Phase 3 covered the engineering effort to write the application that would analysis the historical data and calculate excess MW and running drives.
- Stage 4 involved engagement and communication with the operating centres to obtain input into the project.
- Stage 5 involved integrating the application into Alcoa's daily management process.
- Stage 6 covers the requirement to support the application as the process plant changes.

4.1 PHASE 1 - PROJECT PLAN

The project planning phase was based on Stage 1 (Project Plan) of the Assessment Handbook. The handbook details key points that should be covered in the plan, which are: What is required, when will it be done, who will do it and what resources are required (Assessment Handbook 2011, 11).

4.1.1 Method

The planning stage of the project involved initial introductions to Alcoa employees and discussion on potential projects that would be of value to Alcoa. During these meetings the general objectives and constraints of the dissertation project were discussed and a range of possible energy efficiency projects were presented by Alcoa. The excess drive monitoring project was chosen as it was viewed as a potential high value project for Alcoa. Taking on a project that was of clear value to Alcoa acknowledges the support that they were providing and assists with gaining support within the organisation to complete the project. It also complimented my current employment as a Control System engineer on secondment to Alcoa to support deployment of new MES. A large part of my work involves the management and analysis of historical process data for presentation of Key Performance Metrics (KPI) and online analysis of process performance. It was decided to use my experience in this area to utilise the existing historical process data and newly deployed data analytic tools to develop an application to monitor and report on excess drive use.

4.1.2 Result

The project plan consisted of a set of user requirements that covered the scope of the drive monitoring application and its functionality. The scope was defined as 3 of the refinery operating centres: Digestion, Clarification and Precipitation. The functionality was defined to cover how the application would detect excess running drives; how the excess MWh and dollar costs would be calculated; and how the results would be displayed and accessed by refinery users.

4.2 PHASE 2 – DATA GATHERING

The data gathering phase was based on the methods detailed in Stage 3 (Understanding energy use) and Stage 4 (Opportunities identification) of the Assessment Handbook. Stage 3 involves the gathering of energy and business data to form an understanding of energy use in the business (Assessment Handbook Australia 2011, 43). This understanding is then used as a basis for opportunity identification and previously mandatory reporting under the now repealed Energy Efficiency Opportunities Regulations 2006. Stage 4 involves the identification of possible energy efficiency improvements and the development of plans for the detailed investigation stage (Assessment Handbook Australia 2011, 74). For stage 4 the assessment handbook details requirements for opportunity evaluation against business payback criteria and the development of implementation plans. As neither of these activities were required as part of this project stages 3 and 4 were incorporated into a single stage.

4.2.1 Drive Grouping

The drives were grouped by process function and the drive groups were then ranked according to installed kW capacity. Due to the 44-year-old age of the plant, most of the drives do not have individual power metering connected back to the control system. Therefore there was no way to accurately determine the average power consumption of individual drives over time. To understand the estimated energy use for a drive the rated capacity given on the drive name plate was used, it is assumed that this would provide a reasonable assessment of the overall energy consumption as most drives would be running at around 80-90% of rated capacity. The drive details, including name, process function and rated capacity were obtained from a spreadsheet provided by Alcoa. Grouping the drives by process function potentially allowed for smaller drives to be included in the application. Small drives are individually insignificant but when grouped by process function e.g. washer overflow pumps, the energy consumption of the group can become significant and potentially yield useful opportunities for reducing energy consumption. The grouping exercise reduced the size of the assessment from 900 individual drives to 138 groups of drives representing individual process functions. The largest process group was the Mill Drives with an installed capacity of 13,800 kW, which accounted for 11% of the installed capacity and there were a small number of groups of less than 10 kW.

4.2.2 Pareto Analysis

A Pareto distribution was performed on the 138 groups to identify the groups that accounted for 80% of the drive energy installed capacity. The Pareto principle broadly assumes that 80% of affects can be attributed to 20% of causes. For this assessment it would be expected that 20% of the drive groups would account for 80% of the energy consumption. A Pareto assessment is a fast and reasonably simple process. If the resulting distribution fits the expected 80/20 ratio a detailed analysis of the 20% of causes can lead to significant improvements to the 80% of affects. The Pareto assessment of the drive energy consumption identified 32 groups that accounted for 80% of the energy consumption, these 32 groups represented 23% of the 138 groups. The 32 drive groups were presented to Alcoa for discussion. Alcoa commented that the 32 groups represented a site wide assessment that did not offer visibility on drive energy use by operating centre, a request was made for the Pareto distribution to be repeated by operating centre. The Operating Centres are managed as separate business groups with daily production targets and performance monitoring using key performance indicators. Completing the assessment in this manner allows for refinery management to drill down to compare performance between operating centres and it can be used to increase awareness of the energy and cost impact of excess drive use within the Operating Centre. The revised Pareto distributions by operating centre produced 41 groups for assessment across all operating centres, these are detailed Appendix A.

Drive grouping and Pareto analysis covered the intent of the data gathering stages of the assessment handbook. The drive details and data was gathered from Alcoa and the Pareto analysis showed how energy use was distributed across the drive groups.

4.2.3 Results

The installed drive capacity across the 41 groups consisted of approximately 360 drives with an installed capacity of approximately 87 MW. This is still a significant number of drives and it was unlikely that a detailed assessment of drive use could be undertaken within the time allowed for this project. The list of drive groups was presented to Alcoa and the issue with time limitations was discussed with them. It was agreed with Alcoa that the study would be limited to the Digestion, Clarification and Precipitation operating centres. These 3 process areas represent the liquor circuit of the Bayer alumina refining process where the majority of drive work involves pumping of slurry from digestion through clarification and alumina rich liquor through the precipitators. After the reduction in study scope the final drive count came to 216. These drive groups are listed in the tables below.

Drive Group	Installed kW	Type	% Installed kW	Pareto Distribution	Number of Drives
Evaporator Feed Pumps	4500	Pump	24%	24%	8
LTD Pumps	3600	Pump	19%	43%	8
Spent Liquor Pumps	3510	Pump	19%	62%	9
Seal Tank	2050	Pump	11%	73%	10
Hotwell Pumps	1650	Pump	9%	81%	9

Table 1: Digestion

Drive Group	Installed kW	Type	% Installed kW	Pareto Distribution	Number of Drives
Filter Feed	3600	Pump	25%	25%	9
35A Filtrate Pumps	2475	Pump	17%	42%	11
Overflow Pumps	2312	Pump	16%	59%	28
UnderFlow Pumps	1459	Pump	10%	69%	40
Thickener L Pumps	895	Pump	6%	75%	6
Thickener Underflows	487	Pump	3%	78%	18
35J Caust Return Pumps	355	Pump	2%	81%	3

Table 2: Clarification

Drive Group	Installed kW	Type	% Installed kW	Pareto Distribution	Number of Drives
45 GL Fill Pumps	2520	Pump	17%	17%	8
45 E SLR Pumps	2520	Pump	17%	34%	8
45T Cooling Water Pumps	2250	Pump	15%	49%	5
45 Cyclone Feed Pumps	1850	Pump	12%	62%	10
45 PT to Hi Pumps	1350	Pump	9%	71%	6
45E Injection Liquor Pumps	1125	Pump	8%	78%	5
45T ISC Circulation Pumps	1125	Pump	8%	86%	15

Table 3: Precipitation

This was essentially a data gathering and organisation exercise that improved understanding of how energy is being used within the refinery pump population. The Evaporator Feed pumps have the largest installed capacity at 4500 kW, Digestion pumps accounted for 15 MW, Clarification pumps 11.6 MW and Precipitation pumps 12.7 MW. The Energy Efficiency Opportunities Handbook details an Information Hierarchy process that describes the process of understanding energy use as “generally a ‘top-down process…” (Assessment Handbook 2011, 44). The top level is understanding total energy use; the second level is energy use by area and time; and the third level is energy information at the process and equipment level, this is illustrated below in Figure 3 – Information Hierarchy (Assessment Handbook 2011, 44). This exercise improved the understanding of energy use by area and at the equipment level.

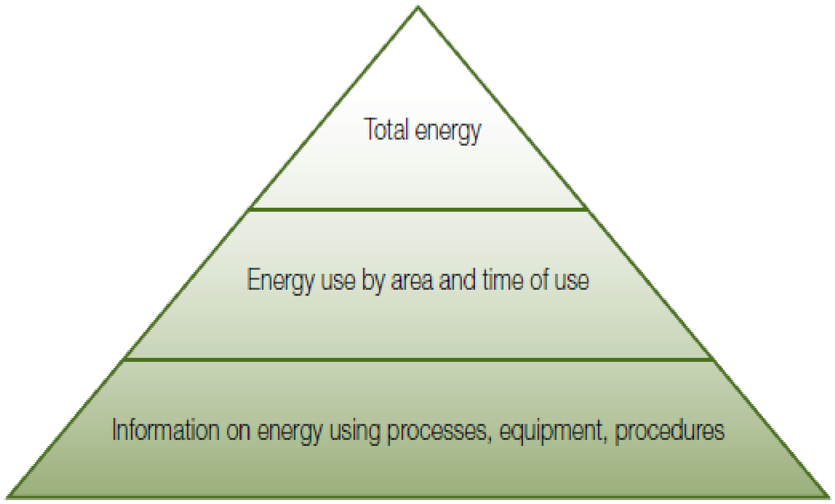


Figure 3: Information Hierarchy

4.3 PHASE 3 APPLICATION DEVELOPMENT

The application development work can be classified as a Stage 6 (business decisions and implementation) effort under the guidelines in the Energy Efficiency Opportunities Handbook. In the context of the handbook implementation is the last stage of the assessment process. For this project the development effort was started in the middle of the process and before extensive communications has started with the broader engineering and operations community. This is not a recommended approach, but it was done for good reason and this is explained in detail in Section 8.5 Communication.

4.3.1 DCS Overview

Modern Distributed Control Systems (DCS) are complex layered network architectures consisting of proprietary industrial computers at the field level to numerous servers, workstations and networking equipment at the higher levels. The diagram shown below, Figure 4: DCS Overview, is a simplified representation of a typical DCS system and has been provided to aid understanding.

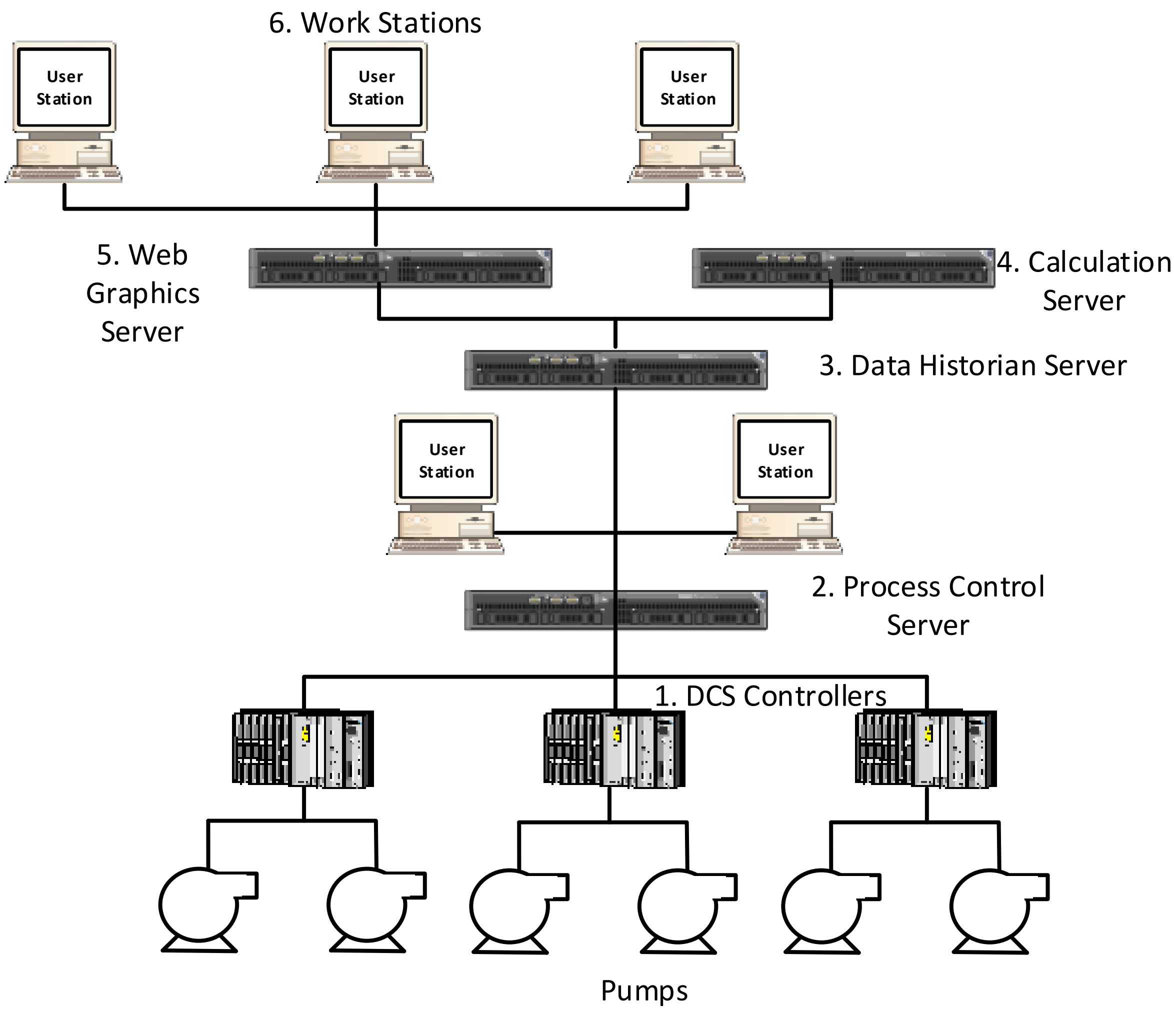


Figure 4: DCS Overview

1. The Distributed Control System (DCS) controllers are industrial computers that control the process. The DCS sends start and stop commands to the pumps based on operator commands or process conditions.
2. The Process control server acts as an interface between the DCS controllers and the user stations.
3. The data historian server gathers and archives data from the process control servers.
4. The calculation server reads data from the data historian server, runs calculations and writes the results back to the data historian.

5. The web graphics server allows graphical interface to the data historian for viewing of data from workstations on the corporate network.

4.3.2 Application Overview

An application was developed in Visual Basic .NET and hosted in a calculation server with read/write data connections to the process history database. The logic for the application was written using simple conditional and iterative constructs for status comparison and to loop through a list of drives. A text file was used to store the drive tags and other associated drive details such as the estimated MW, reference tag for the drive current (if available) and the process group that the drive is allocated to. Each drive and its associated details are stored on separate lines of the text file. The application reads a single line of the text file, executes the logic using the parameters read from the text file and then moves to the next line of the file. This repeats until all lines of the file have been read. Use of a text file to store the drive details results in a smaller application as the drive information does not need to be coded into the application. It also allows for ease of maintenance and support as a user with no programming knowledge can add or remove drives from the application by simply editing the text file. Data tags[2] were created in the historical data system to store the results obtained from each run of the application and existing tags were used to read the drive status, the tags are detailed below:

- Drive Status Tag – The application reads the drive state from this tag, either RUN or STOP
- Drive Group Count – The application writes the number of drives running in the group to this tag.
- Drive Group Target – The application reads the maximum allowed number of drives that can be running from this tag.

[2] The data tags reside in the process data historian. Each tag stores historical data from a single process variable or calculation. A single tag can store many thousands of data points going back a number of years.

- Drive Group Excess MW – The application writes the excess MW for the group to this tag. The excess MW are calculated after comparing the Drive Group Count to the Drive Group Target. If the target is exceeded the excess MW is calculated based on the number of excess drives running and the estimated MW consumption of the extra drives.
- Overview tags were built for the application to write the total number of drives running in excess and the excess MW for each operating centre. This provides the means to quickly compare performance across operating centres.

A meeting was held with Alcoa to set the initial values for the Drive Group Targets and to identify drives that are physically configured in duty standby arrangements. In a duty standby arrangement there should always be 1 drive off, if all drives in the duty standby group are running then this is counted as an excess running drive and the associated excess MW are calculated. The drive groupings identified in Stage 2 can contain multiple sets of duty standby pumps

The application and its supporting process control architecture are detailed below in Figure 5 Application Architecture:

- The STEM price is read into the historian database every 30 minutes from an external web server.
- The historian data base and calculation server function as described in Figure 3.
- The text file resides on the calculation server and contains the pump data tags, the estimated pump kW and the historian tags were the results of the calculations are written to.

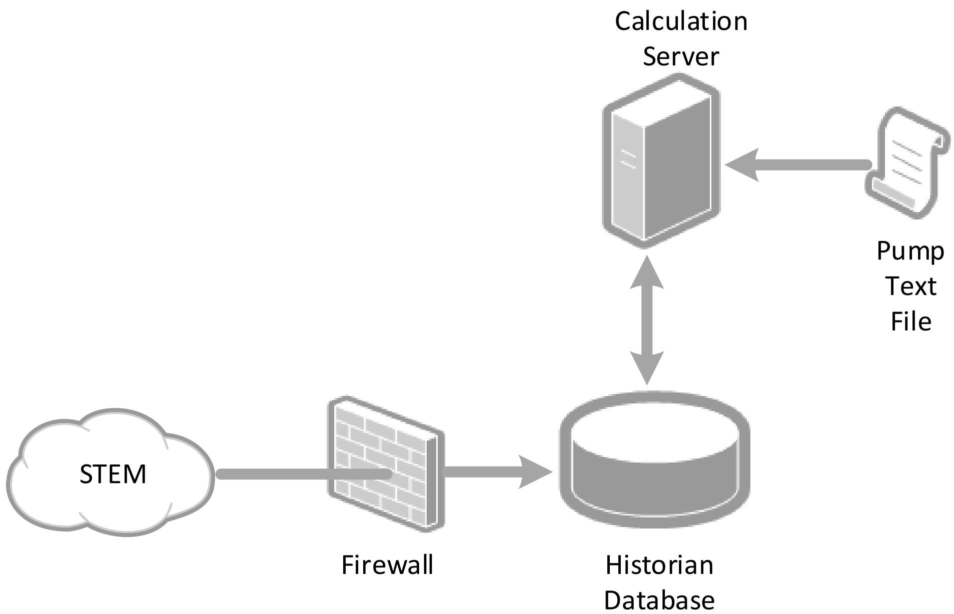


Figure 5: Application Architecture

4.3.3 Application Run Frequency

The calculation server hosts many thousands of process related calculations from simple periodic averages to more complex analytics. These calculations are scheduled to run at regular intervals ranging from 1 hour to 1 month. Calculations can also be manually run in order to back calculate over time at set intervals, this enables missed periods to be recalculated or a historical profile to be developed for newly created calculations. The drive monitoring application is scheduled to run each day at 6:00 AM, which is the start of the first shift. At 6:00 AM a snapshot of the drive statuses is taken and the excess parameters are calculated. The 6:00 AM snapshot is less representative than a longer term average, but it does indicate potential issues with running drives, which can then be addressed through Alcoa's standard start of shift workflows.

4.3.4 Graphics

A set graphics was developed to display the output of the application and to provide an overview of the individual drive states. The graphics are html based and can be easily accessed through a web browser from any Alcoa connected computer. The ease of access allows the results of the application to be viewed by a wide range of people from senior plant management to control room operators. The graphic sources data from the process history database and an imbedded time control allows the user to step back through previous days to view past results. Refer to Appendix B for screen shots of the 4 graphics that were created for this project.

Figure 6: Graphic Layout details the standard content and layout of the graphics with a description on each of the displayed items.

Figure 6: Graphic Layout

1. Displays the total estimated power usage for the monitored drives.
2. The STEM price averaged over the last day.
3. The number of drives running in excess of target.
4. The estimated excess MW consumption.
5. Estimated cost of the excess MW over 24 hours.
6. The ideal (target) number of drives that should be running in the drive group.
7. The actual number of drives running in the drive group.
8. The estimated excess MW in the drive group.
9. Run/Stop indication for each drive in the drive group.
10. Description of the drive group.

4.4 PHASE 4 SITE REVIEW MEETINGS

A series of meetings were held with each of the 3 operating centres included in the application. The purpose of the meetings was to present the work done to date and obtain input from the operating centre engineers and management. The meetings were conducted over a number of weeks as it was often difficult to schedule meetings as many of the required participants are busy with crucial process issues during the day. A set of initial results were also prepared to demonstrate the capabilities of the application and its potential value as a monitoring tool.

4.4.1 Initial Results

The application was developed and validated on a small sample of drives to identify and correct any issues and errors. Once the validation process was completed the remaining drives were progressively added to the application. The application was then back-calculated from July 16th 2016 to January 1st 2014, this provided just over 2.5 years of data. The back calculation accessed existing drive status data that is archived back several years and used this data to calculate the parameters for this application. The back calculated data was extracted from the historian database into excel spreadsheets for more detailed offline analysis. The raw data consisted of 104 data tags with each tag holding up to 940 points of data, overall this equated to approximately 90,000 individual points of data to be analysed. For ease of handling the data was aggregated into monthly averages using an iterative Excel macro. Normally this type of basic calculation is routinely done within the data historian environment by a dedicated calculation application. I did not have ready access to this application and it was considered desirable to maintain the data in a high resolution raw format for offline analysis. The initial results for each of the 3 operating centres are detailed below in Table 4: Initial Results.

Operating Centre	Excess Pumps Online	Excess MW (Snapshot)	Excess MW/h (Daily Total)

	(Snapshot)		
Digestion	8.2	2.3	54.4
Clarification	7.3	0.64	15.4
Precipitation	3.3	0.55	13.2
Total	**18.8**	**3.5**	**83**

Table 4: Initial Results

These initial results showed potential for significant energy reduction. During a review meeting with senior process engineers it was determined that the excess MW values were far too high. The drive group targets (maximum number of drives allowed to run) had been set too low. The values for the targets had been estimated based on the design parameters for the plant. If a pump set has 3 pumps then only 2 pumps should have run to achieve the rated process flow. Pinjarra has steadily increased production over the years through a variety of efficiency and optimisation projects. These projects would aim to minimise capital expenditure, as a result existing pump sets are not always upgraded. To achieve the increased process flows more pumps must be run, often in excess of the original design.

4.4.2 Trends

The steady increase in the number of pumps running is apparent when the results are trended across the 2.5 years. Figure 7: Initial Excess Run Count, shows a steady increase in excess running pumps over the period, illustrated by the yellow trend line. The majority of the increase has come from Clarification, with Digestion and Precipitation remaining relatively constant. This was raised with Alcoa, as it was expected that all areas would see an increase.

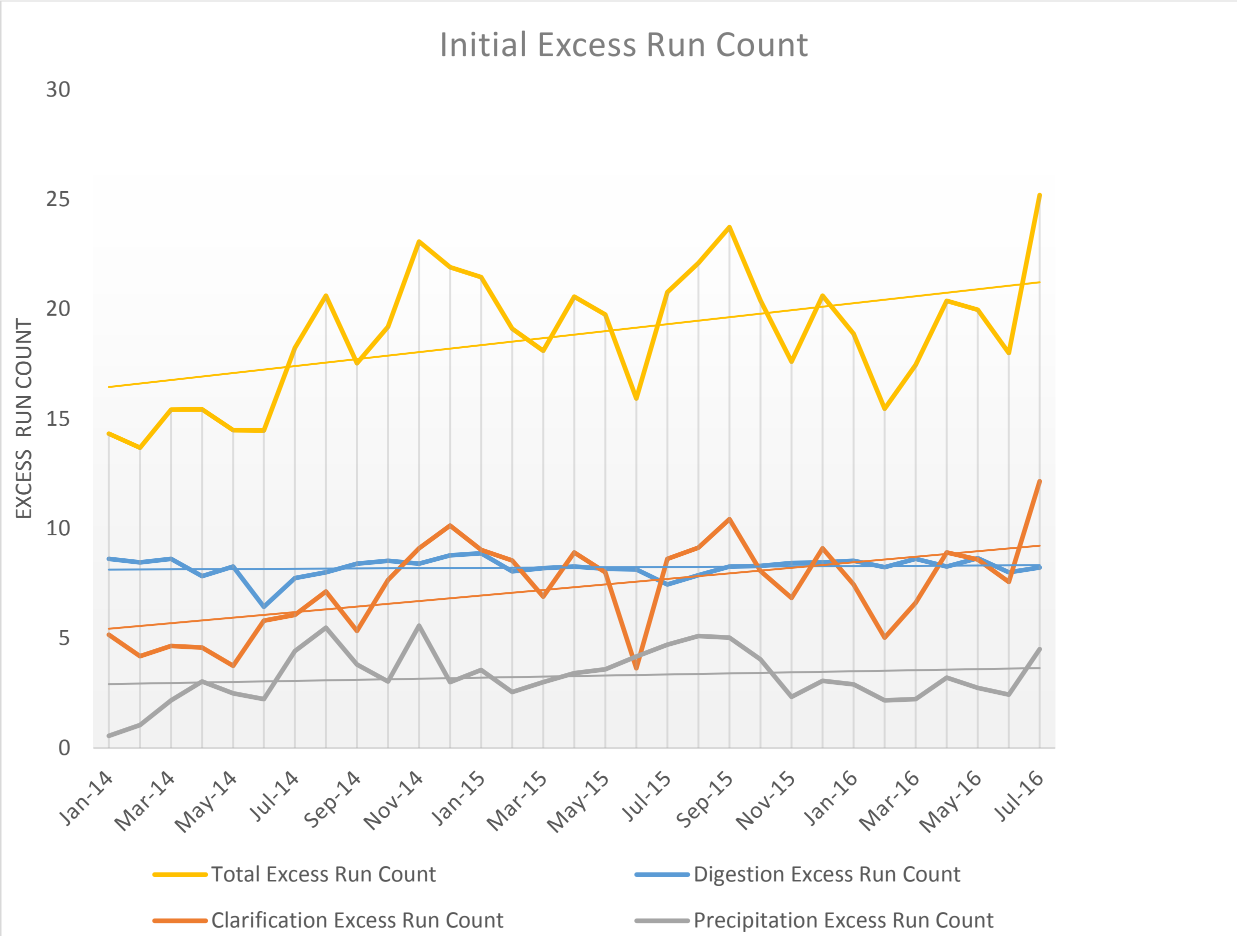


Figure 7: Initial Excess Run Count

Digestion and Precipitation have a smaller number of large pumps with flow control capability, such as VSD drives or flow control valves. The increased flows through these areas has been achieved without needing to run too many additional pumps, whereas Clarification has a large number of smaller pumps, requiring more running pumps to process the increased flows. The pattern of increase is also seen in the excess MW, which is shown below in Figure 8: Initial Excess MW.

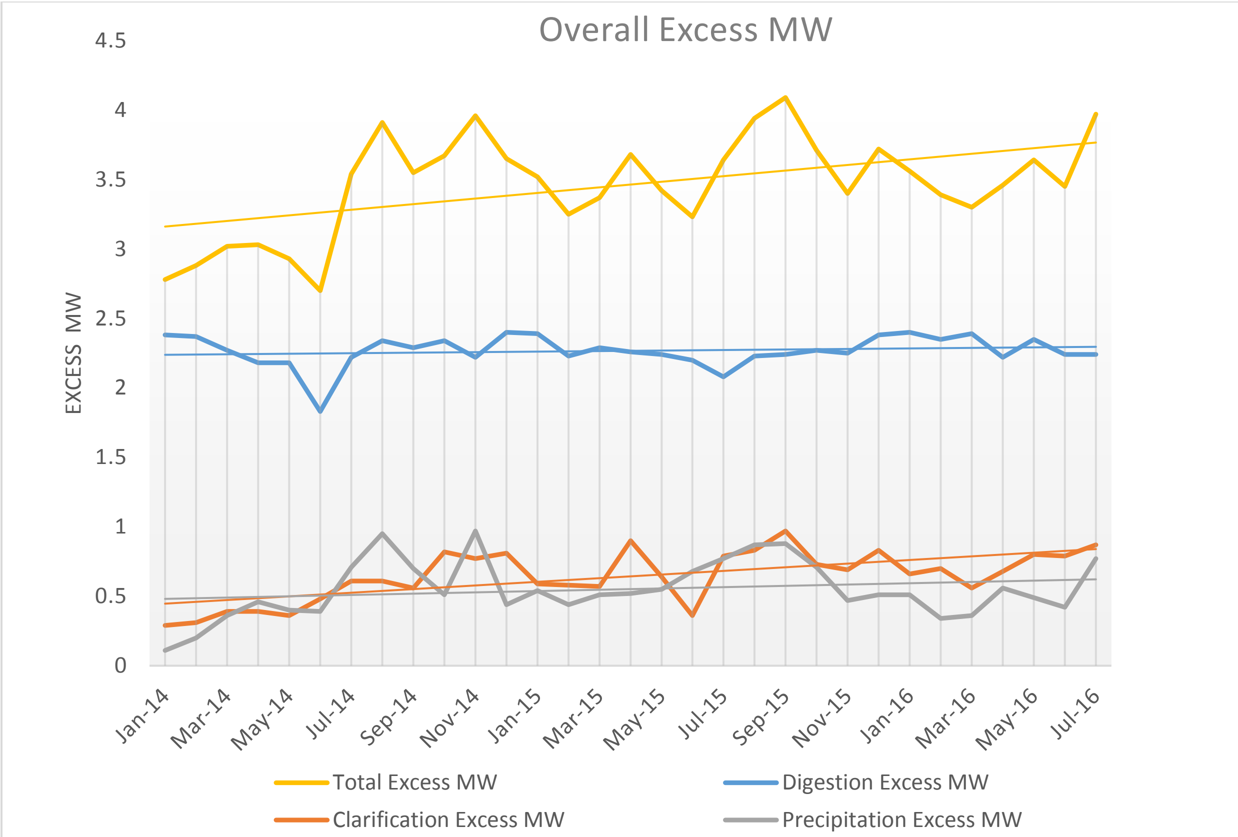


Figure 8: Initial Excess MW

These initial results and the overview graphics formed the basis of the review meetings that were held with representatives from each of the 3 operating centres.

4.4.3 Summary of review meetings

The review meetings were an important part of the overall project as they engaged a range of people in presenting the objectives of the project and receiving feedback for consideration and incorporation into the finished product. Feedback was only sort at a reasonably late phase of the project, around the mid-point. The Energy Efficiency Opportunities Assessment Handbook recommends communication with a wide range of stakeholders at all stages of an energy assessment program (Assessment Handbook Australia 2011, 31). Communication with the broader engineering and operations teams started after the drive monitoring application had been developed. In this instance, having a developed and working application allowed the review meetings to focus on an actual product requiring change rather than a theoretical product. Presenting a working product allowed the intent and functionality to be easily understood by the area management and engineering teams. This allowed direct and pertinent feedback on how the product could be improved.

Meetings were held with each operating centre, during which the application was demonstrated and feedback from the participants was noted. Table 5: Review Meeting Actions summarises the feedback by operating centre.

Operating Centre	Request Details	Status
Digestion	Change LTD pumps to a dynamic target based on process flow	Actioned
Digestion	Change evaporator, hotwell and seal tank pumps to dynamic target based on the number of digester units online	Actioned
Digestion	Add the condensate return pumps to the application	Cancelled
Clarification	Add the H1-6 pumps to the application.	Actioned
Clarification	Add the oxalate area to the application	Cancelled
Precipitation	Remove cooling pumps from the application	Actioned
Precipitation	Remove the Inter-stage cooling pumps from the application	Actioned
Precipitation	Add the tray underflow pumps to the application	Actioned
Precipitation	Add the CGM pumps to the overview graphics	Actioned
Precipitation	The spend liquor return pump target from 8 to 6	Cancelled
Precipitation	Add 45A condensate liquor pumps to the application	Cancelled
All Areas	Change the application update frequency from daily to hourly	Pending
All Areas	Convert the graphics to the latest version of the graphics package (PRISM Plus)	Actioned
All Areas	Add process trends to the overview graphics showing excess MW and running pumps over a number of days	Pending

Table 5: Review Meeting Actions

5 PHASE 5: APPLICATION DEPLOYMENT

At the time of writing this dissertation the application had not been deployed. The plan is to start the deployment of the application in early October 2016. The planned steps for the deployment are:

1. Complete the agreed application changes.
2. Run the modified application in test mode for 1-2 weeks.
3. Send communications to each operating centre explaining what the application does, why it has been developed, how it is to be used, and the date for operational deployment.
4. Modify the Daily Visual Management (DVM) boards to include a line for excess running pumps. [3]
5. Start reviewing the number of excess pumps running at the daily meetings and start assigning actions to have excess pumps taken off.

These steps were managed by Alcoa without my involvement. This type of change is common in Alcoa and there are well established processes and understanding on how to bring effective change to a complex operating environment. Incorporating a review of excess running pumps into the daily meetings is crucial to realising any MW and cost savings that might be achievable with this application. The potential savings are visible to management, who are likely to set expectations for change in order that the savings can be achieved.

[3] The DVM boards are large white boards that are updated each day with key process performance indicators. The boards are reviewed each day by operations management where issues are identified and actions assigned.

6 PHASE 6: ONGOING TRACKING & ENHANCEMENT

6.1 TRACKING

It is important that any savings attributed to this application are understood and regularly reported to the wider business. The report could detail the number of drives found running in excess then stopped and the estimated savings. Or a simpler approach could be to track the excess MWh over time to determine if it is reducing. Demonstrating the value of the application will support its ongoing use and enhancement and it will support the business case for further projects of a similar nature. This principle is described in the Assessment Handbook under Stage 7 – Tracking and communicating assessment outcomes (Assessment Handbook 2011, 106).

6.2 ENHANCEMENT

The application will need to change in order to reflect ongoing changes in the process plant: new drives will need to be added, obsolete drives removed, drive installed capacities changed and Drive Group Targets adjusted. The application was designed to be easily modified so that it can be kept up-to-date with process changes and remain useful for many years to come. If the application cannot be supported it will become increasingly irrelevant and its use will diminish.

At the time of writing this dissertation changes were being made to the application, with engineering started for the addition of 3 operating centres: Calcination, Power House and Residue. The drive groups had been identified and work had started on the data historian and graphics. In future it is planned to expand the application to support demand side response to STEM price variations that may occur during periods of high electricity demand. This will require the application to run more frequently than once per day so as to provide high frequency data that can be acted on to achieve potential savings.

7 FINAL RESULTS

The items that were completed in time for this dissertation (refer to Actioned Items listed in Table 12) were included into the application and a back calculation was run once more over the January 2014 to July 2016 period. The results were extracted to Excel and aggregated to monthly averages and overall averages. The overall averages for excess MW and excess pumps online are shown below in Table 6: Overall Results.

Operating Centre	Excess Pumps Online (Snapshot)	Excess MW (Snapshot)	Excess MW/h (Daily Total)
Digestion	0.4	0.15	3.54
Clarification	7.7	0.73	17.41
Precipitation	2.9	0.46	11.2
Total	**11**	**1.34**	**32.1**

Table 6: Overall Results.

These results were reviewed with Alcoa to identify Operating Centres and Pump Groups for further attention. Areas of interest were pumps groups with high excess MW and pumps groups that now had zero excess MW. The groups with continuing high excess MW clearly warranted further investigation, it could be that these pumps represented a genuine opportunity for operational change to reduce pump use or that the targets were still set too low. The pump groups with zero excess MW should be checked to ensure that the targets have not been set too high or if the target could be calculated based on process conditions. These detailed reviews and the associated work with the operating centres would only start after the application had been deployed to the operating centres.

The key points of interest taken from these results are:

- Overall daily excess MWh fell from 83 to 32.

- Digestion reduced from 54.4 MWh to 3.5 MWh.
- Clarification increased from 15.4 MWh to 17.4 MWh.
- Precipitation reduced from 13.2 MWh to 11.1 MWh.

The reduction in excess MWh in Digestion is of interest as this area was now using calculated pump targets based on process conditions. Any residual excess MW may now represent an opportunity for reduction through operational change by taking pumps offline. The increase in Clarification can be attributed to the addition of the 35H pumps to the application. The reduction in Precipitation can be attributed to the removal of the cooling water and Inter-Stage-Cooler (ISC) pumps from the application.

7.1 DIGESTION DETAILED REVIEW

The enhancements that were carried out on the Digestion section of the application resulted in a significant drop in the excess MW being recorded by this area. The application has now been tuned to the point where the genuine and achievable opportunities are now becoming apparent. Table 7: Digestion Results by Pump Group shows the annual weighted averages for excess MW and the number of days the pump online targets were exceeded. Weighted averages were calculated to account for 2016 results finishing in July.

Pump Group	Excess MWh per Annum (Weighted Average)	Excess Pump Days per Annum (Weighted Average)
CRD Condensate Pumps	0	0
Spent Liquor Pumps	0	0
Seal Tank Pumps	3.5	0.8
Evaporator Transfer Pumps	10.8	1
Hotwell Pumps	13.5	2.6
LTD Pumps	423.3	45.7
Evaporator Feed Pumps	740.3	80.7

Table 7: Digestion Results by Pump Group

The evaporator feed pumps, hotwell pumps and seal tank pumps are now using calculated targets based on the number of digester units online. The targets are set to match the number of installed pumps and then reduced by 1 for each digester unit that is offline. The evaporator feed pumps appear to offer the greatest opportunity both in terms of excess MW and excess pump days. There were on average 81 days of the year when excess evaporator feed pumps were being run resulting in 740 MWh of excess power consumption. The target for the Liquor to Digestion (LTD) pumps is calculated based on the process flow rate to the digesters, if the flow drops below a pre-set limit the target is reduced by 1 pump. On average there were 46 days of the year when excess LTD pumps were being run resulting in 423 MWh of excess power consumption. The remaining pump sets appear to offer only moderate opportunities for MWh reduction. The seal tank, evaporator transfer and hotwell pumps average approximately 8 MWh per annum of excess power consumption. The CRD condensate and spent liquor pumps have zero excess use, there might be an opportunity to use calculated targets to release efficiency opportunities based on process conditions.

7.2 CLARIFICATION DETAILED REVIEW

Clarification had the highest excess MW of the 3 operating centres and the highest number of excess pumps on line. As a result of the review meeting the only adjustment made in Clarification was the addition of the 35H pumps, which added another 550 MWh per annum to the excess. The pumps in Clarification are typically smaller than the other operating centres and are configured in duty standby sets consisting of 2, 3 or 4 pumps. As detailed in Section 4.4.2, to achieve higher flow requires more pumps to be run. This has resulted in the application over estimating the excess MW, as such the potential savings are lower than the initial estimate. For the value of the application to be realised the clarification targets should be set based on process conditions, so as to more accurately estimate the potential savings.

Clarification has perhaps only limited opportunities for improvement with this application. However it is worth considering that running a greater number of small pumps, in general, will be less efficient than running a smaller number of large pumps. Perhaps the long term improvement opportunity for clarification is to install larger pumps, by highlighting this point the application has potentially still added value.

The per annum excess MWh and days with excess pumps running are listed below in Table 8: Clarification Results by Pump Group.

Pump Group	Excess MWh per Annum (Weighted Average)	Excess Pump Days per Annum (Weighted Average)
Causticiser Return Pumps	50.1	11.6
35C 10 Underflow Pumps	62.4	36.7
L Pumps	71.7	20.1
35F 30 Pumps	77.2	123.4
35C 40 Underflow Pumps	148.2	167.0
35C 30 Underflow Pumps	161.5	150.6
35C 50 Underflow Pumps	162.4	199.0
35C 20 Underflow Pumps	163.3	132.8
35C Unit 3 Pumps	194.6	112.4
35C Unit 5 Pumps	310.8	156.2
35C Unit 4 Pumps	338.0	166.3
35H Pumps	554.3	87.6
35C Unit 1 Pumps	555.4	203.6
35A Filtrate Pumps	580.3	127.0
35D Filter Feed Pumps	2113.1	195.9

Table 8: Clarification Results by Pump Group

7.3 PRECIPITATION DETAILED REVIEW

Precipitation has the second highest excess daily MWh and excess pumps days it. The cyclone feed pump group had the highest per annum excess MWh and excess pump days at 2173 and 282 respectively. The review meeting resulted in the removal of the cooling water pumps and the ISC pumps from the application. The targets for these pumps had been set at the number of installed pumps and there was considered to be no reasonable opportunity to save MWh by monitoring these pumps. The Injection Liquor Pumps and Spent Liquor Return pumps have no excess MWh as the targets have been set to equal the number of installed pumps. These pumps have been left in the application as it was considered useful for the area engineer to have them displayed on the power summary graphic. The Cyclone Feed pumps recorded an average annual excess of 2173 MWh, which was the highest amongst all of the pump groups in the study. There are 10 Cyclone Feed pumps configured in 5 duty standby sets with 2 pumps per set. Excess MW are recorded when both pumps in a set are running, for the Cyclone Feed pumps this occurs on most days, and on average 282 days per year. These pumps are worth investigating to determine if the additional use is required for production or if the pumps are often used in excess of requirement. The Green Liquor Fill pumps also have a high average annual excess at 1245 MWh. There are 8 Green Liquor Fill pumps and the maximum running target is set at 6 pumps. A review of the raw data extracted from the historian showed that on average there are 7 pumps running for 165 days of the year, giving an excess of 1 pump. For the remaining days of the year there were 6 running pumps, which is at target. For roughly half of the time the number of running pumps equals the maximum target, for the remainder of the time the target is exceeded by one pump. The Green Liquor Fill pumps represent an excellent opportunity for further investigation – is the additional use justified for half of the year or can one pump be taken off? The per annum excess MWh and days with excess pumps running are listed below in Table 9: Precipitation Results by Pump Group.

Pump Group	Excess MWh per Annum (Weighted Average)	Excess Pump Days per Annum (Weighted Average)
Injection Liquor Pumps	0	0
Spent Liquor Return Pumps	0	0
PT to Hi Pumps	72	13
Tray Underflow Pumps	210	129
Green Liquor Fill Pumps	1245	165
Cyclone Feed Pumps	2173	282

Table 9: Precipitation Results by Pump Group

7.4 POTENTIAL ENERGY SAVINGS

The purpose of this project was to produce an application that could be used daily by operations and management to reduce excess pump use and ultimately reduce energy use. At the time of writing this dissertation the application was in the process of being deployed to operations, so no operational history is available to use as a basis to calculate the potential annual savings. An estimation was made using the data that was obtained from the last back calculation of the application, which was done after the application had been modified to incorporate requested changes raised during the review meetings. The back calculation was run from 1st January 2014 until July 2016, the results are shown in Table 7: Overall Results, with the daily MWh savings being:

- Digestion, 3.54 MWh
- Clarification, 17.41 MWh
- Precipitation, 11.2 MWh
- Total, 32.1 MWh

These values do not represent the total potential energy saving as further work is required to modify the targets for Clarification and Precipitation so that they represent how the process is being run. The targets for Digestion were changed from static to dynamic and are now adjusted based on process conditions. This reduced the excess daily MWh from 54.4 to 3.54. If the same dynamic target calculations were applied to Clarification and Precipitation then a reduction in estimated energy consumption would also occur in these areas. Numerous factors and assumptions could be made to arrive at an estimate of the potential energy savings, but without operational history no reasonable estimate can be made.

8 RECOMMENDATIONS

8.1 BUSINESS CASE

For a project of this nature to succeed in a large operationally complex industrial process there has to be a clear business case and strong sponsorship from management. Without this the effort will certainly fail and the calculated results will become just-another-number consigned to irrelevance amongst hundreds-of-thousands of other process data points. The business case for this project was defined by the desire to reduce electricity cost by reducing the number of running drives in the process. Operation and engineering management know that, at times, more drives are running than required, but at any given instant it is difficult to identify excess drive use and quantify the cost. The application met the business requirement by identifying drives that are potentially being used in excess and calculating the MWh and dollar cost of the excess use. The project was sponsored by the Pinjarra Process Coordinator Manager, who has overall responsibility for the refinery process operations. The Process Coordinator Manager is able to bring in new operational initiatives and make direct instruction for immediate changes to be made in the operation of the process. During the project the Process Coordinator Manager assisted in these areas:

- Gathering the drive data for the initial engineering
- Obtaining the approvals to access the process control system at an engineering level
- Communicating the project intent and value to the broader organisation
- Organising meetings with operations and engineering personnel
- Bringing about organisational change so that reviewing and acting on excess running pumps becomes a daily part of plant operations
- Generally providing assistance, advice and insight into how the organisation and process are run.

- Post deployment support to ensure that the application continues to be used by operations on a daily basis.

As a business leader the Process Coordinator Manager has to balance the need to maintain flow rates whilst ensuring the process is being run safely and efficiently. Taking pumps off can seem counter intuitive to operations, who are primarily focused on safety and flow rates. The sponsorship and communication from the Process Coordinator Manager was invaluable in ensuring that operations understood the need and value that can be obtained by using this application as part of daily operations management.

8.2 PERFORMANCE METRIC

Cost is the ultimate metric and over time Alcoa would expect to see a reduction in cost as a result of deploying this application. The excess cost calculation produced by this application is the product of the STEM price and the estimated excess MWh. Accessing if use of the application has resulted in a dollar cost saving is difficult to impossible as the STEM price varies based on electricity demand and available generation. Figure 9: Stem Price shows the monthly average of the STEM price over a 2.5 year period and it shows that the STEM price is highly variable, ranging from the mid 30 dollars to over 60 dollars per MWh. Cost is therefore an unreliable indicator of long term performance. Using MWh as the long term performance metric is more consistent as it only varies based on the number and types of drives being used in excess. The application also stores excess MWh for each drive group allowing for long term performance tracking to be carried out at a lower level.

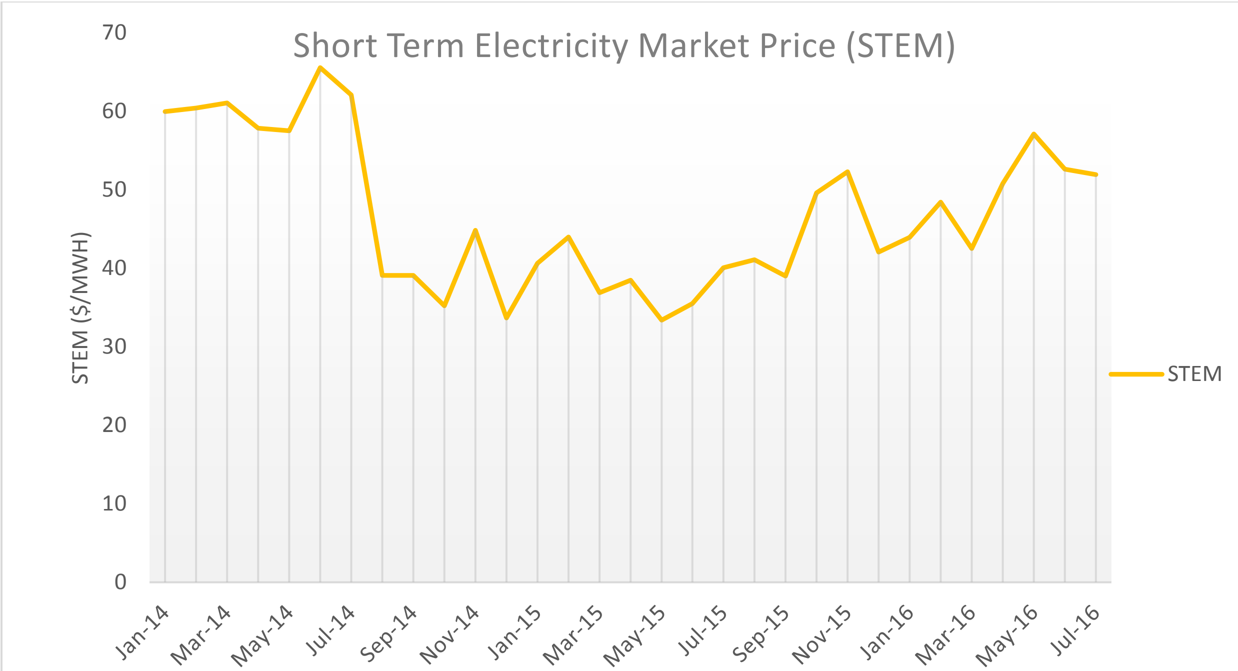


Figure 9: STEM Price

The business case still needs to be expressed by reporting achieved cost reductions. For example an aggressive short term demand-side management response to extreme high STEM prices may result in significant cost savings for only a small reduction in MWh. Cost is therefore a useful and meaningful metric to maintain alongside MWh.

8.3 ENGINEERING

The engineering effort for this project covered the identification of the drives, development of the Visual Basic application, creation of the data points in the historian database and development of the web graphics for data visualisation.

The drive identification work involved collating the drives into common process groups and summating the installed kW capacity for each group. The summated capacity were then used in a Pareto analysis to identify the drive groups that accounted for 80% of the installed capacity. Initially the Pareto analysis was done as a single group for all of the drives on site. This approach did not consider that the process is run from 5 main operating centres, each with a large number of pumps. If the application was to be useful in bringing about an operation change by reducing pump usage, then it would need to be developed for each operating centre as opposed to a site wide approach. The Pareto analysis and any drive collation effort needs to be done separately so as to make it relevant and useful for each operating centre. Focusing on each operating centre assists in bringing a culture change in operations to focus on drive use and it increases the size of the potential benefit for the entire site. Grouping the drives by process group allowed for smaller pumps to be included in the application, for example in Clarification the washer underflow pumps have an average installed capacity of 90 kW, which at Pinjarra is a relatively small pump. However the combined capacity of the 20 washer underflow pumps is 1400 kW making the group large enough to include in the study. The large pumps are an obvious inclusion and will make a significant impact on excess MW consumption if too many pumps are running, but it is more likely that a large group of small pumps will more often have excess units running, making the inclusion of these pumps a good opportunity for improvement.

For the application to be effective it must be used at least once per day by the operations teams and site management. To support frequent use by a large number of users the results have to be presented in a format that is easy to understand and readily accessible. To achieve this requirement the results were displayed in web based graphics that could be accessed via a web browser on any computer connected to the Alcoa business network.

8.4 ENHANCEMENTS

The application made limited use of dynamic targets in Digestion, where the maximum number of drives that can run in a group is calculated based on process conditions. This could be expanded to include more drive groups so that the number of pumps that are allowed to run is adjusted based on flows and other process conditions. The cost of the excess MWh is calculated using the STEM spot price, which is updated into Alcoa's systems every 30 minutes. During periods of high demand the spot for electricity can peak at over twice the average value. From January 2014 to July 2016 the average MWh price was $47, but on the 1st of July 2014 the price peaked at $100 per MWh. To respond to periods of high spot prices the application could be expanded to support demand response as described in 8.2. The application could be modified to include logic that identifies the pumps that if stopped would achieve the greatest electricity savings. The pumps that are identified as potential candidates to be stopped should be listed by process area along with the potential MWh and cost saving. This information should be available on web based graphics and supported with other information such as total electricity imported to site; total electricity being generated on site; the net difference; and trends showing changes in electricity consumption and pricing over recent hours.

MES technology has wide potential to improve energy monitoring and performance. Improvements could be made through detailed analysis of the historical data to uncover trends and relationships or near real time calculations could be developed to provide KPI and performance monitoring applications. Identifying the opportunities is an important early step. The process that was detailed in the Energy Efficiency Opportunities Handbook could be used to engage broadly within Alcoa to find new opportunities for development. The calculation server has entropy and enthalpy functions that could be used to calculate thermodynamic performance, this could include isentropic efficiency, exergy or equipment energy intensity. Energy performance could be modelled at a process unit level enabling comparison between identical units. Any future opportunity has to pass the test of producing data that can be used operationally. Otherwise the effort is lost amongst the hundreds-of-thousands of other data points.

8.5 COMMUNICATION

Communication is an important component of change management. It engages people in the process and seeks to bring them along rather than imposing change upon them, which greatly increases the likelihood of the project succeeding. It is generally considered good practice to start communications early and to include as many people as possible and to ensure that a wide range of roles and responsibilities are covered.

For this project the communications with the broader Alcoa operations and engineering teams started later than would normally be recommended. Engineering of the application and graphics was completed to an intermediate level before communication and engagement was started with the area operations and engineering teams. This approach has potential disadvantages in that the change could be viewed as being imposed and the latest operational and engineering knowledge from the broader organisation is not included in the preliminary design. The approach also had advantages in that when the communications were started the basis was a preliminary application that was running and returning results. Rather than discussing a concept we were discussing something that existed. In general concepts can more easily be discussed with engineers but operations prefer discussions on real tangible items. By developing the application on 3 process areas we were able to demonstrate its functionality and receive meaningful feedback on how to improve the product.

The communication with the broader organisation was sponsored and organised by the Process Coordinator Manger. Communication started with emails describing what was being done and providing links to the web based graphics so that participants could view and familiarise themselves with the product prior to the meeting to discuss in greater detail. The feedback from the review meetings typically included requests for the addition or removal of pumps sets based on actual operational requirements. The initial engineering of the project used a Pareto analysis on installed pump size to identify the units for inclusion in the application. This approach produced a good list of initial units that was then refined and improved on through this communication process. Feedback also included requests for the addition of very small pumps of less than 10 kW installed capacity and to include new sets of pumps on the overview graphic but not to calculate excess MW. These requests feel outside of the project objective to reduce excess MW consumption but they were included in the finished product so as to facilitate use of the application by the operations and engineering teams.

Members of the operations team expressed concern that they would be expected to always act on the output of the application without consideration for the complex environment in which they work. This was addressed by explaining that the application only highlights potential excess pump use for further investigation.

8.6 TOTAL COST CONSIDERATIONS

Excess pump use is not just a problem of increased electricity use and cost, there are other cost considerations such as increased maintenance cost, capital replacement costs and in some cases increased packing water cost. The business case for development and use of an application of this nature is improved if these additional costs can be estimated and incorporated with the electricity cost to give an overall estimation of the cost of excess pump use.

Excessive pump use can also be an indication of process problems, as flow lines scale-up or slurry pumps wear out, pumping effectiveness deteriorates, in order to maintain flow more pumps have to be run. Running the additional pumps serves to mask the developing process problem and potentially make the inevitable maintenance work more difficult and costly. Therefore detecting excess pump use can reduce power costs, reduce maintenance costs and potentially highlight the need for earlier preventative maintenance. Excess pump use can also be used in a business case for increased capital expenditure. If operations must run all the installed pumps to achieve the required process flow then there is no standby capacity to cover for planned maintenance or unplanned breakdown. In this situation it is likely that a high number of small pumps are being run, which is less efficient than running a smaller number of large pumps. Installing larger pumps to maintain the process flow and overall process reliability is therefore a good potential investment.

9 SUMMARY

This project has demonstrated a consulting and engineering approach that can be used to engage with a complex heavy industrial business to deliver technology solutions to improve energy efficiency. Pinjarra uses hundreds of pumps to transport material through an alumina refining process. Monitoring these pumps to ensure that only the minimum number are being used to meet process flow targets is impractical for plant engineers and operators. The attention of these highly trained professionals is often focused on more complex process problems, the optimal number of running pumps is often of considerably lower importance. The consulting phases of this project produced a list of drives grouped by process function and operating centre. The engineering phase produced a Visual Basic application that uses near term historical data to monitor the number of running drives in each group. Any excess drive use within a group is indicated on html graphics along with calculated excess MWh and cost.

An accurate estimate of potential savings can only be achieved after the application has not been running long enough for sufficient data to be gathered and once the remaining 3 operating centres have been added. At the time of writing this dissertation the application was still being deployed to plant operations and only back calculated data was available that showed theoretical excess drive usage from January 2014 to July 2016 for 3 operating centres. Pinjarra process flows are increasing year-on-year and to achieve these increased flows many pump sets are being run in excess of original design but not in excess of requirement. The back calculated data mainly used theoretical design targets for the number of drives that should be running, which resulted in an over estimate of excess drive use. Over time the targets will be adjusted to represent the actual minimum number of drives required to meet process flow targets. Once this has been done a more accurate estimate of potential savings can be developed.

The application has the potential for further development to add functionality to respond to high peak electricity prices. The application could respond to high electricity prices by listing the highest energy consuming drives, which would support short term demand-side management and potentially deliver significant cost savings.

Completing this project has developed my engineering consulting skills and has provided insight into how complex industrial process are managed. My previous work experience has mainly been focused on industrial process control and historical data analytics with only a minimal exposure to consulting and change management. This project has demonstrated the importance of management sponsorship and communication when developing and deploying products to be used regularly by operations. Without the right sponsorship and communication this project would have produced numbers that would have been lost and rendered irrelevant amongst hundreds of thousands of other numbers. Instead this project has produced an MES application that can be used to improve energy efficiency and reduce business cost. It has potential in any industrial process using large numbers of pumps and the concept of using MES to monitor usage and compare against ideal targets could be applied to a wide range of industrial equipment and process inputs.

APPENDIX A: DRIVE PARETO BY OPERATING CENTRE

Drive Group	Installed kW	Type	% Installed kW	Pareto Distribution	Number of Drives
Mill Drives	13824	Drive	64%	64%	8
Mill MPP Drives	3545	Drive	16%	80%	14

Table 10: Milling and Mining

Drive Group	Installed kW	Type	% Installed kW	Pareto Distribution	Number of Drives
Evap Feed Pumps	4500	Pump	24%	24%	8
LTD Pumps	3600	Pump	19%	43%	8
Spent Liquor Pumps	3510	Pump	19%	62%	9
Seal Tank	2050	Pump	11%	73%	10
Hotwell Pumps	1650	Pump	9%	81%	9

Table 11: Digestion

Drive Group	Installed kW	Type	% Installed kW	Pareto Distribution	Number of Drives
Filter Feed	3600	Pump	25%	25%	9
35A Filtrate Pumps	2475	Pump	17%	42%	11
Overflow Pumps	2312	Pump	16%	59%	28
UnderFlow Pumps	1459	Pump	10%	69%	40
Thickener L Pumps	895	Pump	6%	75%	6
Thickener Underflows	487	Pump	3%	78%	18
35J Caust Return Pumps	355	Pump	2%	81%	3

Table 12: Clarification

Drive Group	Installed kW	Type	% Installed kW	Pareto Distribution	Number of Drives
OBF Vacuum Pumps	1110	Vacuum Pump	26%	26%	6
Washer Feed Pumps	670	Pump	16%	42%	4
Washer Overflow Pumps	669	Pump	16%	58%	2
UnderFlow Pumps	508	Pump	12%	70%	12
35U Filter Feed Pumps	225	Pump	5%	75%	3
BR Product Pumps	264	Pump	6%	81%	2

Table 13: Oxalate

Drive Group	Installed kW	Type	% Installed kW	Pareto Distribution	Number of Drives
44 Filter Repulp Pumps	4000	Pump	37%	37%	8
44 Filter Vacuum Pumps	2520	Vacuum Pump	23%	60%	8
B44 Filtrate Pumps	1575	Pump	14%	74%	5
B44 Injection Liquor Pumps	1000	Pump	9%	84%	2

Table 14: Filtration

Drive Group	Installed kW	Type	% Installed kW	Pareto Distribution	Number of Drives
45 GL Fill Pumps	2520	Pump	17%	17%	8
45 E SLR Pumps	2520	Pump	17%	34%	8
45T Cooling Water Pumps	2250	Pump	15%	49%	5
45 Cyclone Feed Pumps	1850	Pump	12%	62%	10
45 PT to Hi Pumps	1350	Pump	9%	71%	6
45E Injection Liquor Pumps	1125	Pump	8%	78%	5
45T ISC Circulation Pumps	1125	Pump	8%	86%	15

Table 15: Precipitation

The ISC circulation pumps fell outside of the 80% cut-off for inclusion in the study and were initially not included. Alcoa requested that they be included as the ISC group consisted of 15 individual pumps that as a group had the potential for excess use.

Drive Group	Installed kW	Type	% Installed kW	Pareto Distribution	Number of Drives
Calciner Blowers	8255	Blower	62%	62%	9
Vacuum Pumps	1740	Vacuum Pump	13%	75%	5
Calciner PD Blowers	855	Blower	6%	81%	5

Table 16: Calcination

Drive Group	Installed kW	Type	% Installed kW	Pareto Distribution	Number of Drives
Air Compressor	3630	Compressor	37%	37%	4
Boiler Feed Pumps	3200	Pump	32%	69%	3
Boiler FD Fans	1350	Fan	14%	82%	6

Table 17: Powerhouse

Drive Group	Installed kW	Type	% Installed kW	Pareto Distribution	Number of Drives
CWR Pumps	5500	Pump	39%	39%	11
Sand Plant	3975	Compressor	28%	67%	17
ST Underflow Pumps	2490	Pump	18%	84%	10

Table 18: Residue

APPENDIX B: GRAPHICS

Overview Graphic

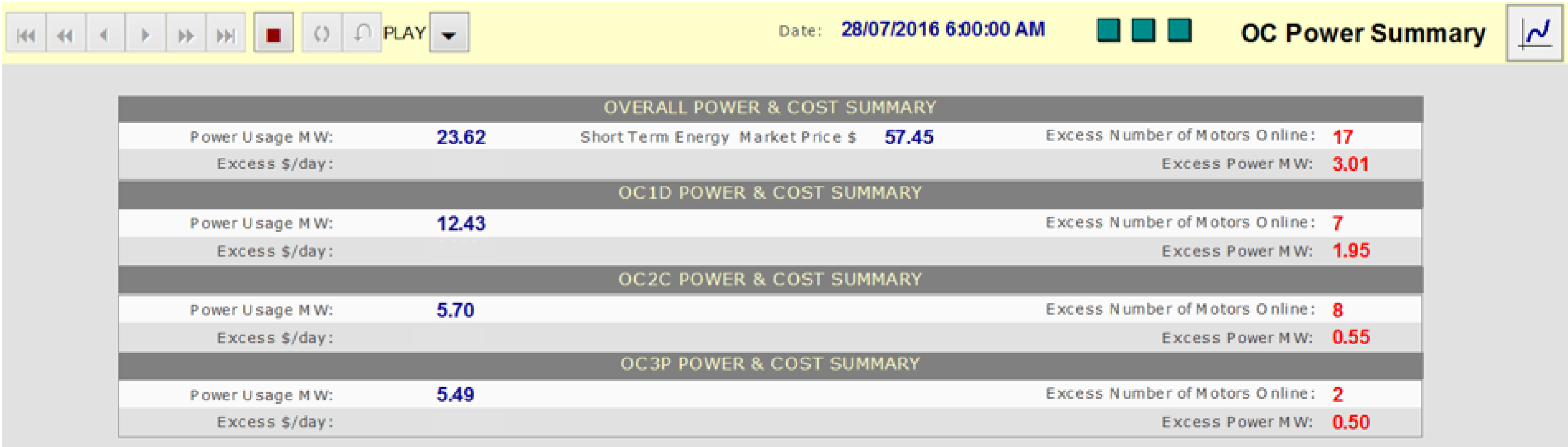


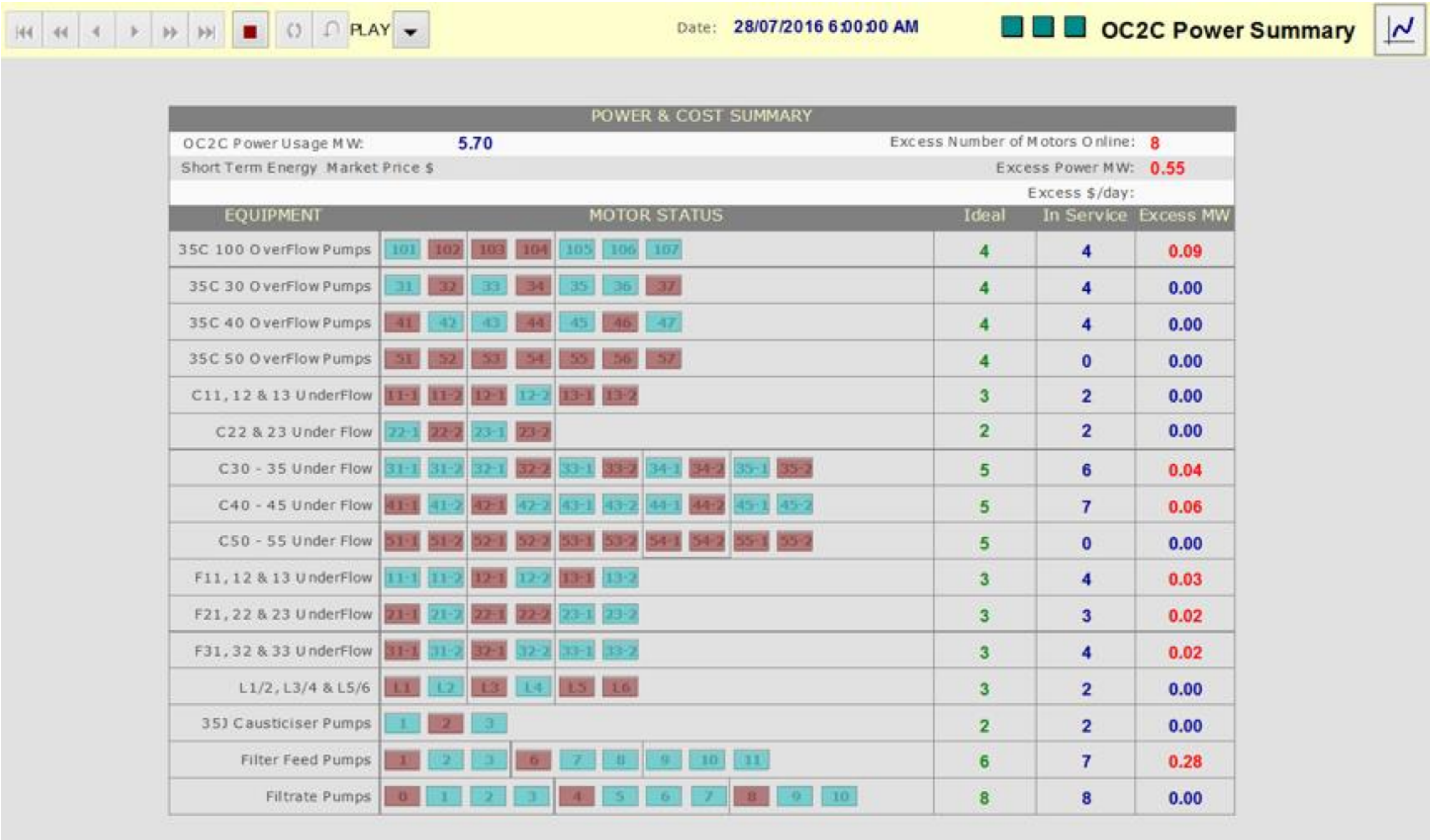
Figure 10: OC Power Summary

Digestion Graphic

EQUIPMENT	MOTOR STATUS	Ideal	In Service	Excess MW
Spent Liquor Pumps	11 12 13 21 22 23 31 32 33	8	7	0.00
LTD Pumps	11 12 21 31 34 41 51 56	8	6	0.00
Evap Feed Pumps	11 12 21 31 34 41 51 56 61 71 78	7	10	1.20
Hotwell Pumps	11 12 21 31 41 51 61 71 81	5	9	0.75
Seal Tank Pumps	11 12 21 22 31 32 41 42 51 52	9	8	0.00

Figure 11: Digestion Power Summary

Clarification Graphic



EQUIPMENT	MOTOR STATUS	Ideal	In Service	Excess MW
35C 100 OverFlow Pumps	101 102 103 104 105 106 107	4	4	0.09
35C 30 OverFlow Pumps	31 32 33 34 35 36 37	4	4	0.00
35C 40 OverFlow Pumps	41 42 43 44 45 46 47	4	4	0.00
35C 50 OverFlow Pumps	51 52 53 54 55 56 57	4	0	0.00
C11, 12 & 13 UnderFlow	11-1 11-2 12-1 12-2 13-1 13-2	3	2	0.00
C22 & 23 Under Flow	22-1 22-2 23-1 23-2	2	2	0.00
C30 - 35 Under Flow	31-1 31-2 32-1 32-2 33-1 33-2 34-1 34-2 35-1 35-2	5	6	0.04
C40 - 45 Under Flow	41-1 41-2 42-1 42-2 43-1 43-2 44-1 44-2 45-1 45-2	5	7	0.06
C50 - 55 Under Flow	51-1 51-2 52-1 52-2 53-1 53-2 54-1 54-2 55-1 55-2	5	0	0.00
F11, 12 & 13 UnderFlow	11-1 11-2 12-1 12-2 13-1 13-2	3	4	0.03
F21, 22 & 23 UnderFlow	21-1 21-2 22-1 22-2 23-1 23-2	3	3	0.02
F31, 32 & 33 UnderFlow	31-1 31-2 32-1 32-2 33-1 33-2	3	4	0.02
L1/2, L3/4 & L5/6	L1 L2 L3 L4 L5 L6	3	2	0.00
35J Causticiser Pumps	1 2 3	2	2	0.00
Filter Feed Pumps	1 2 3 6 7 8 9 10 11	6	7	0.28
Filtrate Pumps	0 1 2 3 4 5 6 7 8 9 10	8	8	0.00

Figure 12: Clarification Power Summary

Precipitation Graphic

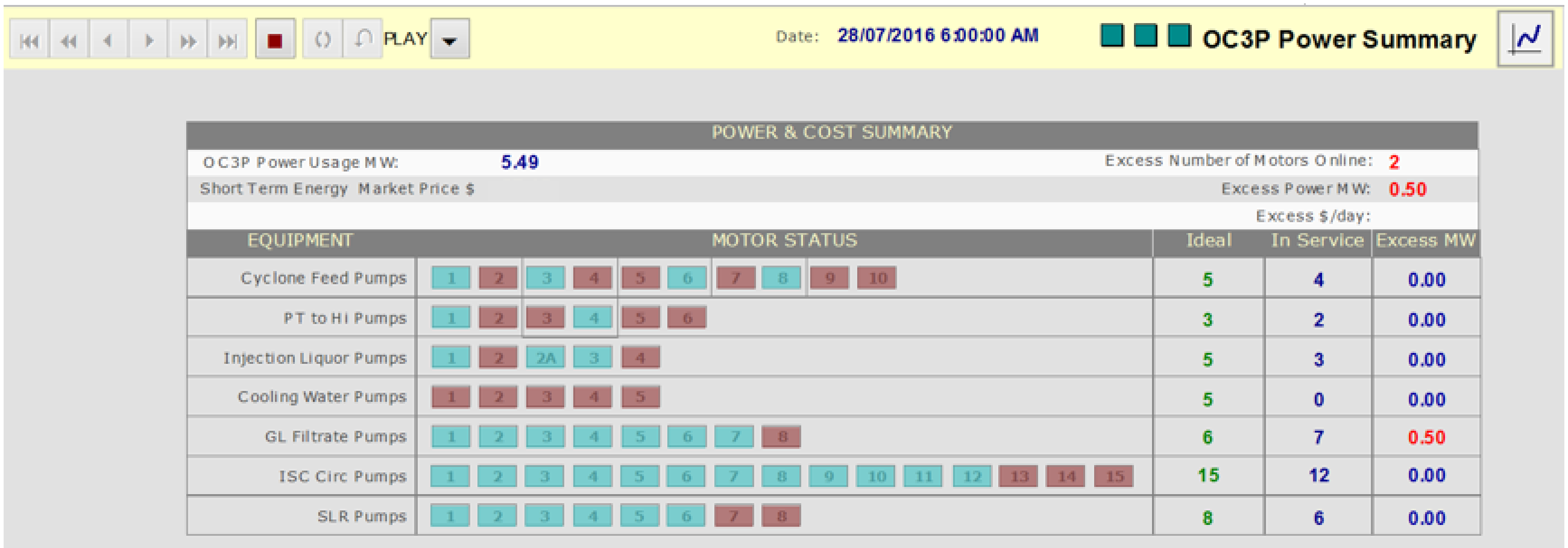


Figure 13: Precipitation Power Summary

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